Deep-Diving California Sea Lions: Are They Pushing Their Physiological Limit?

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Award Number: N000141210633

LONG-TERM GOALS

This project will contribute to our understanding of oxygen management and the underlying physiological mechanisms of oxygen management in marine mammals. This information is essential if we are to interpret and understand the limits of dive performance, foraging ecology, and the ability of breath hold divers to adapt to environmental change and disturbance. The concept that most dives are aerobic in nature and do not exceed an aerobic dive limit (ADL - dive duration associated with the onset of post-dive blood lactate accumulation) has dominated the interpretation of dive behavior and foraging ecology over the past 30 years (Kooyman et al., 1980; Costa et al., 2001). However, because of technical difficulties, the ADL has rarely been measured. Instead, researchers have had to resort to estimations of total O_2 store depletion, i.e., calculated ADLs (cADLs) (Costa et al., 2001; Weise and Costa, 2007). In this study we will determine the rate and magnitude of O_2 store depletion during dives, and investigate its relationship to heart rate and workload, thereby improving our understanding of O_2 management during diving, specifically the role of lung O_2 stores and O_2 delivery to tissues.

OBJECTIVES

This study will utilize backpack digital recorders to measure blood oxygen depletion, heart rate, and flipper stroke rate in dives of California sea lions during maternal foraging trips to sea from San Nicolas Island. The goals of this research are 1) determination of the rate, pattern and magnitude of blood O_2 store depletion during both shallow and deep dives at sea, 2) documentation of heart rate profiles of shallow and deep dives, and assessment of the relationship between changes in heart rate to blood O_2 profiles, and 3) documentation of flipper stroke rate profiles during shallow and deep dives, and assessment of the relationship of stroke rate to both changes in heart rate and changes in blood O_2 profiles.

APPROACH

Objective 1: In order to calculate the rate and magnitude of depletion of the blood O_2 store during dives, arterial P_{O2} profiles will be obtained from a P_{O2} recorder and intravascular electrode deployed on

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Deep-Diving California Sea Lions: Are They Pushing Their Physiological Limit?	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Center for Marine Biotechnology and Biomedicine Scripps Institution of Oceanography 8655 Discovery Way 215 Scholander Hall La Jolla, CA 92093-0204**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**3**	

sea lions. Venous P_{O2} profiles have already been collected in the PI's current ONR project with California sea lions. As in previous research by the PI with California sea lions and other species (Meir et al., 2009; Meir and Ponganis, 2009), the P_{O2} profiles will be converted to Hb saturation profiles with the use of the sea lion O_2-Hb dissociation curve determined in the PI's current ONR project. In addition to the P_{O2} and Hb saturation profile during a dive, the start-of-dive and end-of-dive % Hb saturations can then be used to calculate the magnitude of blood O_2 depletion during dives based on the net change in % Hb saturation, and the known Hb concentration and blood volume.

Objective 2: ECG profiles will be collected from a second group of freely diving lactating female sea lions. The following indices of heart rate during dives will be measured and compared in shallow vs. deep dives: a) dive heart rate (total number of beats / dive duration), b) maximum heart rate during a dive, c) minimum heart rate, d) time into the dive (% of dive duration) until resting heart rate (70 bpm, Ponganis et al., 1997) is reached, and e) duration of and heart rate during the ascent tachycardia. If possible, heart rate during rest periods will also be measured if females are seen resting on land. Although heart rate will not be measured concurrently with P_{O2} we will compare heart rate and P_{O2} data between dives of similar duration and depth to determine any potential relationship between heart rate and blood O_2 depletion.

Objective 3: Accelerometers will be deployed on females with ECG data loggers in order to evaluate stroke-glide patterns in shallow vs. deep dives and to examine the relationship between heart rate and stroke rate. Although venous P_{O2} will not be measured concurrently with stroke rate, we will compare stroke rate and venous P_{O2} depletion profiles (collected for our previous ONR funded project) between dives of similar duration and depth to determine any potential similarities between stroke rate and venous blood O_2 depletion rate profiles. In addition, we will evaluate whether there is any difference in the relationship of stroke rate vs. venous O_2 depletion in shallow vs. deep dives.

WORK COMPLETED

We are in the initial phase of this project. We are currently planning for our first field season that will take place in November 2012. Supplies have been ordered, the field crew selected and field logistics are in place. Data logger testing and calibrations have started.

RESULTS

We have no new results at this time as our first field season is pending. Our first manuscript on sea lion physiology has been completed and is now in press.

IMPACT/APPLICATIONS

This will be the first study to measure heart rate in a naturally diving sea lion. The deep and long duration dives of the California sea lions from San Nicolas Island will allow us to examine the plasticity of the heart rate and its' relationship to blood O_2 depletion and stroke rate, in a variety of dive types. By examining the relationship between heart rate, blood O_2 depletion and stroke rate we will improve our understanding of O_2 management during diving, specifically the role of lung O_2 stores and O_2 delivery to tissues. Furthermore, examination of P_{O2} profiles in relation to depth and heart rate will assess the potential role of "lung collapse" in preserving oxygen for re-oxygenation of blood during the ascent tachycardia and re-expansion of the lung (McDonald and Ponganis, in press). Knowledge of the role of the lungs in deep dives of otariids as well as assessment of blood O_2

depletion patterns, heart rate responses, and stroke work during deep dives is directly relevant to the performance and trainability of deep-diving sea lions in the Navy's Marine Mammal Program. In addition, it provides the physiological basis to the foraging ecology of these animals, and allows for the evaluation of their ability to adapt to environmental change.

RELATED PROJECTS

This project is building on our findings from our previous ONR funded project "Blood oxygen depletion in California sea lions: How close to the limit?" (award #: N000141010514)

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